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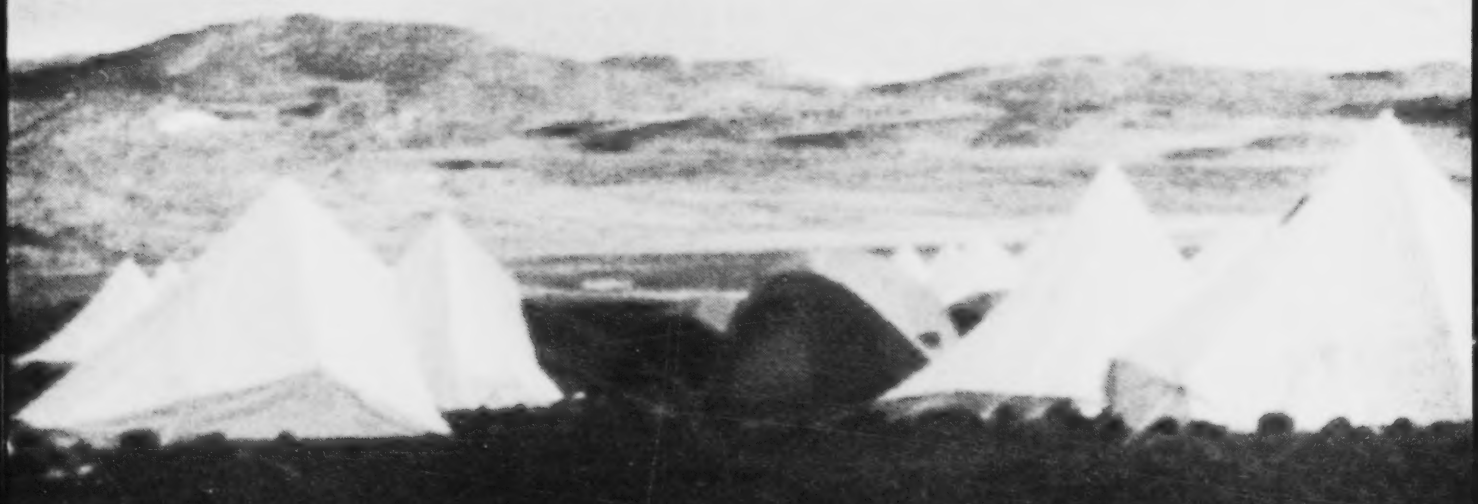
2002



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Authors' addresses

***V.J. McNicoll** (vmcnicol@nrcan.gc.ca)*
***C.R. van Staal** (cvanstaa@nrcan.gc.ca)*
***R. Stern** (rstern@nrcan.gc.ca)*
Geological Survey of Canada
Continental Geoscience Division
601 Booth Street
Ottawa, Ontario K1A 0E8

***D. Lentz** (dlentz@unb.ca)*
Department of Geology
University of New Brunswick
P.O. Box 4400
Fredericton, New Brunswick
E3B 5A3

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Uranium-lead geochronology of Middle River rhyolite: implications for the provenance of basement rocks of the Bathurst mining camp, New Brunswick

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Abstract: Thermal ionization mass spectrometry (TIMS) and sensitive high-resolution ion microprobe (SHRIMP) U-Pb zircon dating techniques were employed in this study to obtain the crystallization age and ages of xenocrystic zircon from a sample of the Middle River rhyolite of the Bathurst mining camp, New Brunswick. A crystallization age of 479 ± 6 Ma constrains the timing of initial volcanism and refines the age of the boundary between the Tetagouche and Miramichi groups. Ages of xenocrystic zircon from Middle River rhyolite and synvolcanic Ordovician plutons range from Cambrian to Archean and indicate a Gondwanan, as opposed to a Laurentian, basement.

Résumé : Des techniques de datation par la méthode U-Pb sur zircon, ayant recours à la spectrométrie de masse par thermoionisation et à la microsonde ionique à haute définition et à haut niveau de sensibilité (SHRIMP), ont été appliquées à un échantillon de la rhyolite de Middle River, dans le camp minier de Bathurst (Nouveau-Brunswick), afin de déterminer l'âge de cristallisation de cette lithologie et l'âge des xénocristaux de zircon qu'elle renferme. Un âge de cristallisation de 479 ± 6 Ma permet de mieux situer l'époque du volcanisme initial et de préciser l'âge de la limite entre les groupes de Tetagouche et de Miramichi. Les âges définis pour les xénocristaux de zircon contenus dans la rhyolite de Middle River et des plutons synvolcaniques de l'Ordovicien varient du Cambrien à l'Archéen, ce qui tend à appuyer l'hypothèse que le socle est de caractère gondwanien plutôt que laurentien.

INTRODUCTION

The Bathurst mining camp, in the northern Miramichi Highlands of northern New Brunswick, lies within part of the Gander zone, one of several tectonic subdivisions within the Canadian Appalachian Orogen (Fig. 1 inset). The oldest sedimentary and volcanic rocks exposed in the Bathurst mining camp are the thick sequence of Cambrian to Lower Ordovician, mainly quartz-rich sandstone and shale of the Miramichi Group (Fig. 1; van Staal and Fyffe, 1995). The Miramichi Group has been intruded by synvolcanic granitoid plutons that range in age between ca. 479 and 465 Ma (Whalen et al., 1998; McNicoll et al., in press). Miramichi Group rocks are disconformably to unconformably overlain by Lower to Middle Ordovician, bimodal volcanic rocks and subordinate sedimentary rocks of the California Lake, Sheephouse Brook, and Tetagouche groups (van Staal et al., 1992; van Staal and Fyffe, 1995; Rogers et al., in press a). These groups represent remnants of different tectonic fragments or blocks that are proposed to have formed in separated parts of the Tetagouche–Exploits back-arc basin (van Staal et al., in press; Rogers et al., in press a). The blocks were structurally juxtaposed during the Late Ordovician–Silurian closure of the basin (van Staal, 1994). The present distribution of units within the Bathurst mining camp is a result of thrusting, nappe stacking, and superimposed folding (van Staal and de Roo, 1995; Fig. 1).

The Miramichi Group has been subdivided, from oldest to youngest, into the Chain of Rocks, Knights Brook, and Patrick Brook formations (Fig. 1, 2; van Staal and Fyffe, 1991; Fyffe et al., 1996). The Chain of Rocks Formation comprises greenish grey, quartz-rich sandstone interlayered with minor green shale, and the overlying Knights Brook Formation is composed of dark grey shale and minor greenish grey sandstone (Rogers et al., in press b). The Patrick Brook Formation comprises volcanogenic, grey to black sandstone and black shale. In the Nepisguit nappe of the Tetagouche block (van Staal et al., in press), the Patrick Brook Formation locally includes a few lenses of rhyolite, the 'Middle River rhyolite' (Lentz, 1997), at its contact with disconformably overlying rocks of the Tetagouche Group (Fig. 2).

Middle River rhyolite

The Middle River rhyolite is located at a key stratigraphic position along the eastern margin of Bathurst mining camp, at the boundary between the Miramichi and Tetagouche groups (van Staal and Rogers, 2000; Fig. 1). Lenses of Middle River rhyolite occur at three places (Lentz, 1997) at the contact between Lower Ordovician, mature, carbonaceous sedimentary rocks of the Patrick Brook Formation (Miramichi Group) and the more calcareous sedimentary rocks of the Vallée Lourdes Member of the Nepisguit Falls Formation (Tetagouche Group; Fig. 2). Pebble to cobble conglomerate of the Patrick Brook Formation occurs discontinuously along the Miramichi Group–Tetagouche Group boundary (Rogers et al., in press b).

Flow-banded, aphyric, Middle River rhyolite consists mainly of very small (<0.5 mm) alkali feldspar spherulites (Lentz, 1997). It is a very specialized, very low temperature, S-type rhyolite that is chemically different than most other felsic volcanic rocks in the Bathurst mining camp (van Staal et al., 1991; Lentz, 1997). The rhyolite has extremely low contents of high field-strength elements (HFSE) and moderately high P content (Lentz, 1997). Based simply on Zr-saturation thermometry (<40 ppm Zr), it has been interpreted as probably being erupted at temperatures less than 700°C (Lentz, 1997). The geochemistry of the Middle River rhyolite suggests that it formed by low-temperature partial melting of a sedimentary protolith (Lentz, 1997).

The age of the Middle River rhyolite is important in providing temporal constraints on the initiation of felsic magmatism, comparing this timing with that of other volcanism in the Bathurst mining camp, and refining the uppermost age of Miramichi Group sedimentation. Ages of xenocrystic zircon from the unit would provide insight into the age and nature of basement to the Miramichi Group. The location of the Middle River rhyolite sample collected for U-Pb dating in this study (z4416) is shown in Figure 1 and UTM co-ordinates are provided in Table 1.

U-Pb GEOCHRONOLOGY

Analytical methods

Thermal ionization mass spectrometry (TIMS) U-Pb analytical methods utilized in this study are outlined in Parrish et al. (1987), and treatment of analytical errors follows Roddick (1987). Analytical results are presented in Table 1, where errors for the ages are reported at the 2σ level, and displayed in the concordia plot (Fig. 3). Zircon fractions analyzed were very strongly air abraded following the method of Krogh (1982). Multigrain zircon fractions comprised between 30 and 35 grains. An attempt was made to minimize the number of grains in a fraction, while ensuring enough radiogenic Pb in the analysis for an acceptable level of precision.

Sensitive high-resolution ion microprobe (SHRIMP II) analyses were conducted at the Geological Survey of Canada using analytical and data reduction procedures described in detail by Stern (1997) and briefly summarized here. Zircons from the Middle River rhyolite sample and fragments of a laboratory zircon standard (Kipawa zircon, 993 Ma) were cast in epoxy grain mounts (GSC mount IP108) and polished with diamond compound to reveal the grain centres. The grains were photographed in transmitted and reflected light, coated with approximately 6 nm of high purity Au, and imaged with a scanning electron microscope equipped with cathodoluminescence (CL) and backscattered electron (BSE) detectors (Fig. 4). The zircons were sputtered using an O^- primary beam focused to a spot size approximately 15 µm in diameter. The isotopic composition of the secondary ion beam was determined by sequential measurements of the following peaks at a mass resolution of 5500 using a single electron multiplier operating in pulse counting mode: $^{196}Zr_2O^+$, $^{204}Pb^+$, 204.1 amu (background), $^{206}Pb^+$, $^{207}Pb^+$, $^{208}Pb^+$, $^{238}U^+$, $^{248}ThO^+$,

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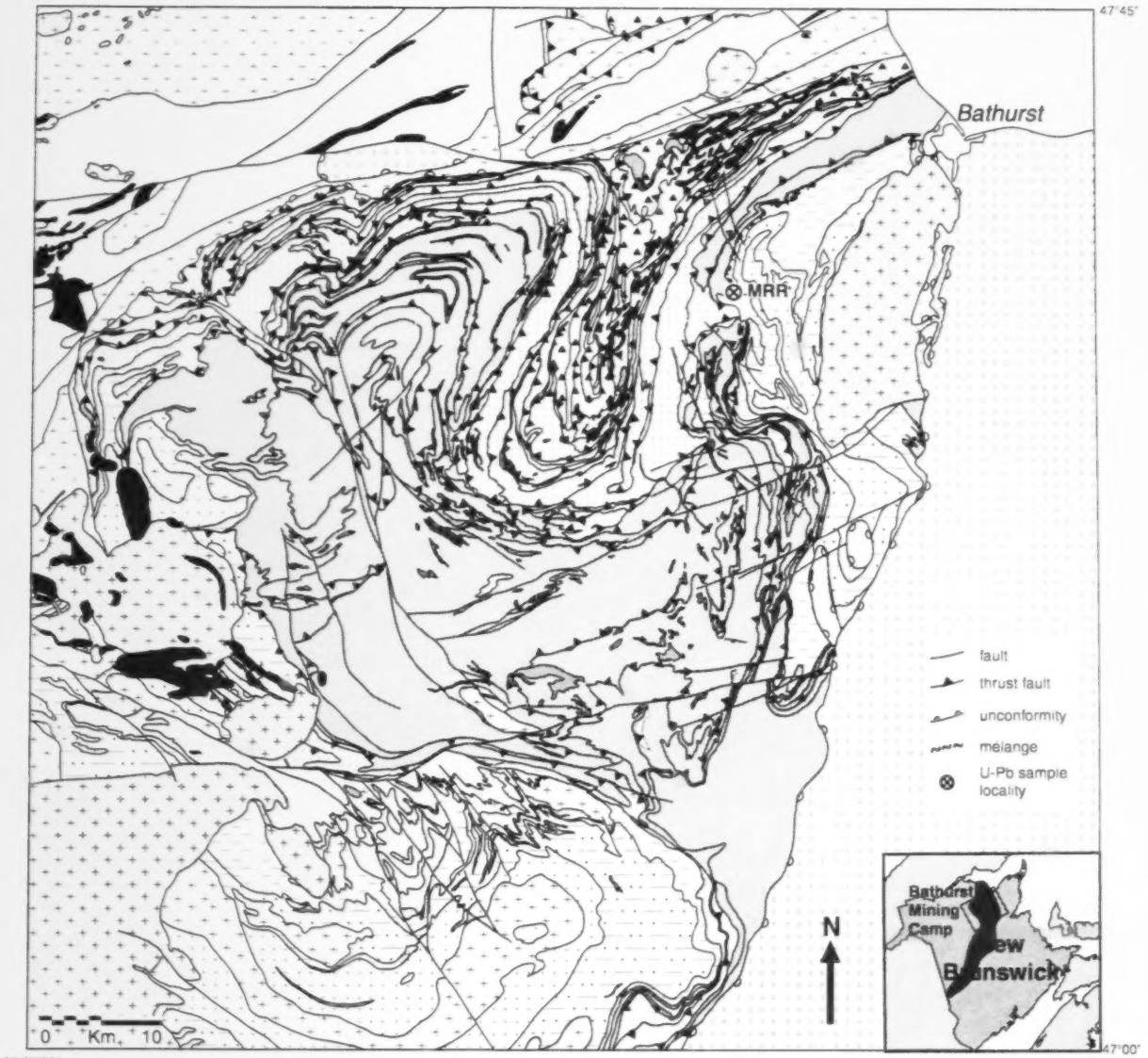

Figure 1. *Geology of the Bathurst mining camp, northern New Brunswick* (modified from *van Staal et al., 2002*). *'X' marks the location of the Middle River rhyolite (MRR) U-Pb geochronology sample. Inset map shows the location of the study area in the Canadian Appalachian Orogen and boundaries of zones within the orogen* (after *Williams, 1979*).

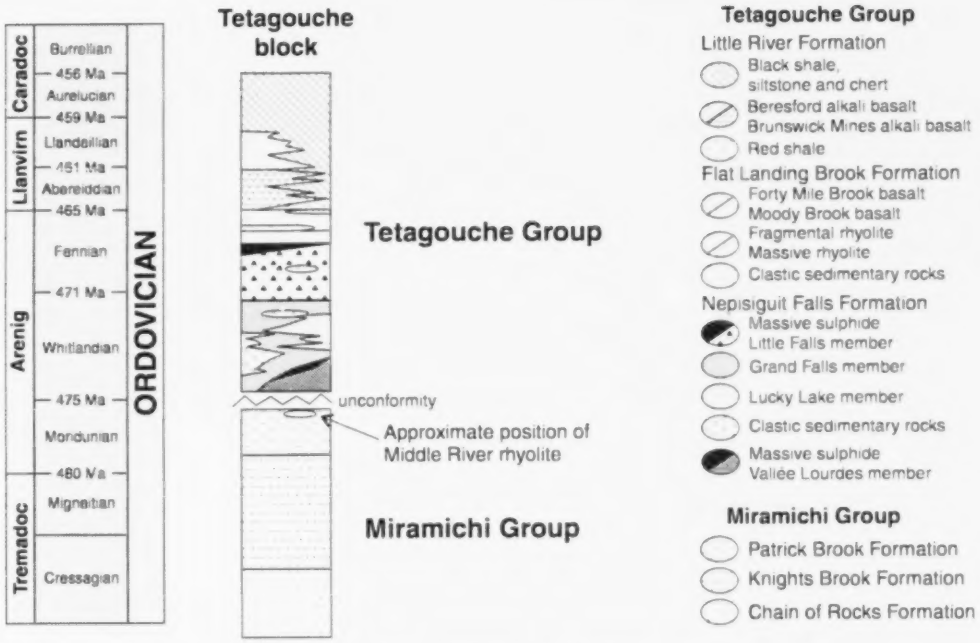

Figure 2. *Schematic stratigraphy of the Miramichi and Tetagouche groups, with approximate location of Middle River rhyolite* (modified from *Rogers et al., in press b).*

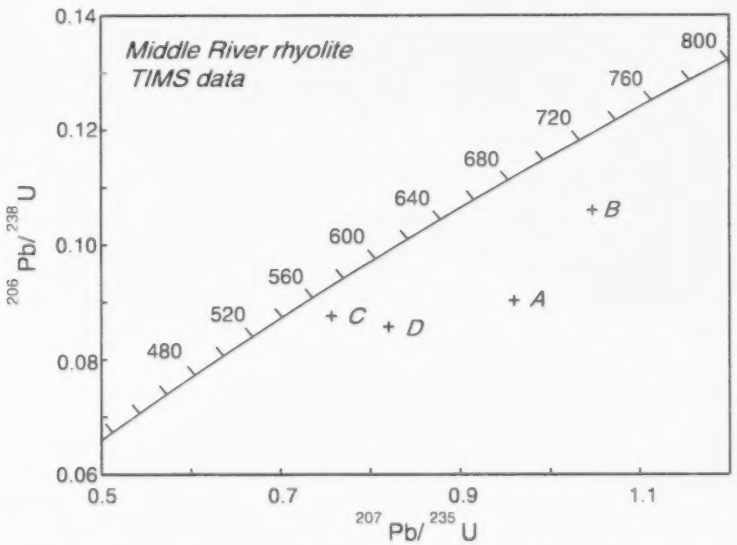

Figure 3. *U-Pb concordia diagram of thermal ionization mass spectrometry (TIMS) analyses of sample z4416. Note that the '+' symbols marking the analyses are larger than error ellipses at 2σ.*

and $^{254}UO^+$. The $^{204}Pb^+$ was monitored to correct for small amounts of common Pb that are largely due to the measured surface blank composition. The Pb/U isotopic ratios were corrected for interelement discrimination by reference to a linear calibration of $^{254}UO^+/^{238}U^+$ versus $^{206}Pb^+/^{238}U^+$ obtained for the standard Kipawa zircons. Common-Pb corrected ratios and ages are reported with 1σ analytical errors in Table 2, which include a ±1.7% external uncertainty associated with discrimination correction of the Pb/U ratios. The $^{206}Pb/^{238}U$ ages for the magmatic analyses have been corrected for common Pb using both the 204 and 207 methods (Stern, 1997), but there is no significant difference in the results (Table 2).

Details of the zircon grains and locations of the SHRIMP spots are given in Table 2. Magmatic and xenocrystic data are plotted in concordia diagrams with errors at the 2σ level (Fig. 5).

U-Pb Results

Multigrain zircon fractions selected for TIMS analysis include delicate, elongate crystals (fraction A), prismatic grains with very sharp terminations (fraction B), stubby prisms (fraction C), and small (approx. 60 μm) stubby prismatic grains (fraction D). All of the zircons analyzed were very clear, high-quality grains with very minor fluid inclusions and no apparent cores or overgrowths under transmitted light. All four analyses are discordant (ranging between 23 and 53% discordant) and are interpreted to contain large inherited components (Fig. 3, Table 1). A crystallization age for Middle River rhyolite cannot be determined from the TIMS analyses.

On the basis of CL and BSE imaging of grains on the SHRIMP mount, most of the zircons have obvious core-rim relationships (Fig. 4). Large core areas overgrown by dark CL, oscillatory-zoned rims are readily apparent (e.g. Fig. 4a–d). There are also zircon grains in the sample that display evidence of more than one generation of overgrowth. For example, grain W-2 (Fig. 4a, b) has a central, diffusely zoned core area surrounded by a light CL, unzoned rim that truncates zoning in the central core. This rim is overgrown by dark CL, oscillatory-zoned rims that were dated at ca. 478 Ma. Grain I-3 (Fig. 4e, f) has a central core with a $^{207}Pb/^{206}Pb$ age of ca. 2390 Ma (spot I-3.2) overgrown by a ca. 560 Ma rim (spot I-3.1), which in turn is overgrown by a very thin, oscillatory-zoned rim (not dated). Rounded xenocrystic grains with little to no magmatic zircon overgrowth are also present in the sample (e.g. grain C-1, Fig. 4g, h). It is interesting to note that no discrete Ordovician magmatic zircons were observed on the SHRIMP mount.

Ages interpreted to reflect Ordovician magmatic crystallization were obtained from thick rims on equant and prismatic to elongate grains with large subrounded cores (Fig. 4a–f). Twelve of the SHRIMP spot determinations on magmatic rims were pooled to obtain a weighted average $^{206}Pb/^{238}U$ age of 479 ± 6 Ma (^{204}Pb-corrected data; 2σ error;

Figure 4. *Backscattered electron (BSE; first image in each pair) and cathodoluminescence (CL; second image in each pair) scanning electron microscope (SEM) images of representative zircons from sample z4416, analyzed using the sensitive high-resolution ion microprobe (SHRIMP):* ***a)*** *and* ***b)*** *grain W-2, consisting of a central zoned core and low CL rims, overgrown by thick, euhedral, dark CL, oscillatory-zoned magmatic rims;* ***c)*** *and* ***d)*** *grain U-2, consisting of a core with an age of ca. 1177 Ma (spot U-2.5), overgrown by thick, oscillatory-zoned, magmatic rims (magmatic-aged spots U-2.2 and U-2.4);* ***e)*** *and* ***f)*** *grain I-3, containing a large core of ca. 2390 Ma age overgrown by a mantle of ca. 560 Ma age (the very thin, strongly oscillatory-zoned exterior rims were not analyzed);* ***g)*** *and* ***h)*** *rounded, inherited grain C-1, whose thickest domain is ca. 963 Ma (the very thin rim and possible core area were not analyzed). The oval spots (central ellipses in BSE images) are SHRIMP pits. Spots outlined with a white dashed line have ages interpreted to reflect Ordovician magmatic crystallization. Labels on the photos refer to SHRIMP analyses listed in Table 2. Scale bars are 50 μm in length.*

Table 1. Thermal ionization mass spectrometry (TIMS) U-Pb analytical data for Middle River rhyolite (sample z4416).

Fraction[1]	Wt. (mg)	U (ppm)	Pb[2] (ppm)	$^{206}Pb/^{204}Pb$[3]	Pb_c[4] (pg)	$^{208}Pb/^{206}Pb$	Isotopic Ratios ± 1σ[5]			Ages ± 2σ, Ma[6]		
							$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
A (30)	8	625	57	2283	12	0.09	0.09031 ± 0.10	0.9600 ± 0.14	0.07710 ± 0.07	557 ± 1	683 ± 1	1124 ± 3
B (35)	15	873	91	17310	5	0.08	0.10598 ± 0.10	1.0455 ± 0.12	0.07155 ± 0.05	649 ± 1	727 ± 1	973 ± 2
C (31)	8	535	46	2558	9	0.07	0.08756 ± 0.10	0.7569 ± 0.14	0.06270 ± 0.08	541 ± 1	572 ± 1	698 ± 3
D (33)	10	263	22	516	28	0.08	0.08572 ± 0.13	0.8202 ± 0.33	0.06940 ± 0.26	530 ± 1	608 ± 3	911 ± 11

Sample Location: UTM zone 19, 281782E, 5269681N
[1]number in brackets refer to number of grains in analysis
[2]radiogenic Pb
[3]measured ratio, corrected for spike and fractionation
[4]total common Pb in analysis corrected for fractionation and spike
[5]corrected for blank Pb and U and common Pb, errors quoted are 1σ (in per cent)
[6]corrected for blank and common Pb, errors quoted are 2σ (in Ma)

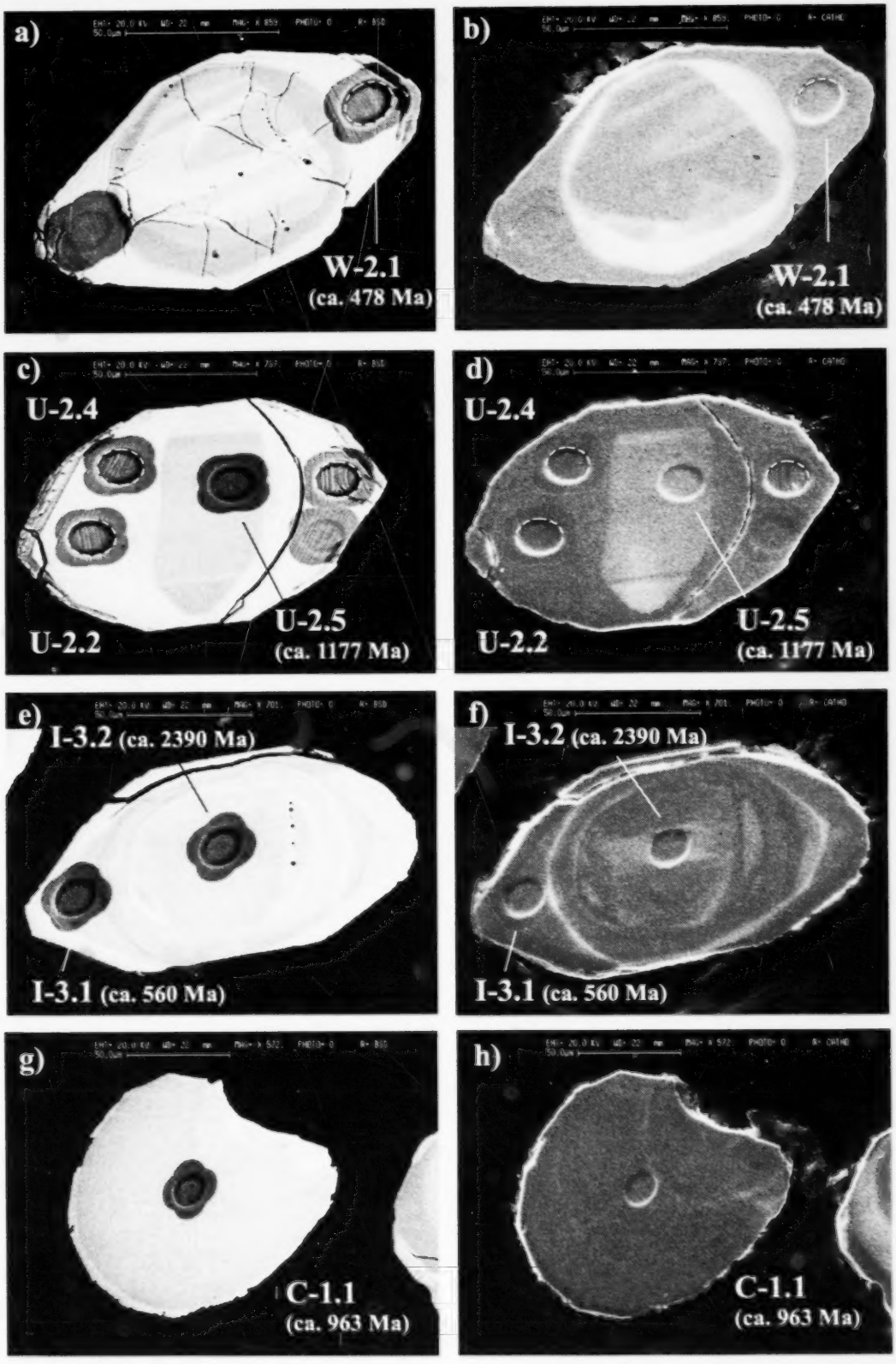
a)
W-2.1
(ca. 478 Ma)
b)
W-2.1
(ca. 478 Ma)
c)
U-2.4
U-2.2
U-2.5
(ca. 1177 Ma)
d)
U-2.4
U-2.2
U-2.5
(ca. 1177 Ma)
e)
I-3.2 (ca. 2390 Ma)
I-3.1 (ca. 560 Ma)
f)
I-3.2 (ca. 2390 Ma)
I-3.1 (ca. 560 Ma)
g)
C-1.1
(ca. 963 Ma)
h)
C-1.1
(ca. 963 Ma)

Table 2. Sensitive high-resolution ion microprobe (SHRIMP) U-Pb analytical data for Middle River rhyolite (sample z4416).

Spot name	Loc.[1]	U (ppm)	Th (ppm)	Th/U	Pb (ppm)	^{204}Pb (ppb)	^{204}Pb/ ^{206}Pb	f206[2]	^{208}Pb/ ^{206}Pb	±^{208}Pb/ ^{206}Pb	^{206}Pb/ ^{238}U	±^{206}Pb/ ^{238}U[3]
Magmatic:												
AA-1.1	rim	2562	25	0.010	177	1	5.31E-06	0.00009	0.0030	0.0005	0.07600	0.00144
W-2.1	rim	3865	36	0.009	270	2	8.32E-06	0.00014	0.0029	0.0004	0.07691	0.00133
V-2.2	rim	3727	33	0.009	263	2	8.11E-06	0.00014	0.0024	0.0004	0.07755	0.00140
U-2.2	rim	2988	13	0.004	208	9	4.84E-05	0.00084	0.0021	0.0013	0.07660	0.00135
N-2.1	rim	479	36	0.074	34	5	1.54E-04	0.00268	0.0186	0.0029	0.07584	0.00159
H-3.1	rim	226	27	0.119	14	0	1.00E-05	0.00017	0.0398	0.0023	0.06330	0.00157
H-3.3	rim	493	34	0.069	34	1	2.92E-05	0.00051	0.0208	0.0021	0.07452	0.00149
I-1.1	rim	673	22	0.033	49	0	1.00E-05	0.00017	0.0094	0.0008	0.07917	0.00168
I-1.2	rim	787	22	0.027	57	1	2.74E-05	0.00047	0.0087	0.0014	0.07852	0.00146
I-2.1	rim	629	39	0.063	44	1	3.09E-05	0.00054	0.0187	0.0015	0.07486	0.00143
U-2.4	rim	3993	31	0.008	290	3	1.00E-05	0.00017	0.0021	0.0004	0.07979	0.00139
U-3.1	rim	1190	22	0.019	85	1	1.00E-05	0.00017	0.0062	0.0005	0.07822	0.00153
T-1.2	rim	2434	25	0.010	162	1	6.69E-06	0.00012	0.0031	0.0005	0.07293	0.00129
AA-1.2	rim	1776	18	0.010	117	1	1.00E-05	0.00017	0.0028	0.0004	0.07265	0.00128
Y-2.1	rim	489	31	0.063	35	0	1.00E-05	0.00017	0.0188	0.0014	0.07777	0.00158
Inherited:												
T-3.1	core	254	113	0.446	22	0	1.66E-05	0.00029	0.1370	0.0053	0.08378	0.00195
I-3.1	old rim	686	19	0.028	57	1	1.62E-05	0.00028	0.0081	0.0012	0.09077	0.00204
W-3.1	core	691	142	0.205	61	11	1.99E-04	0.00345	0.0698	0.0031	0.09125	0.00188
Q-2.1	core	556	439	0.790	58	2	3.59E-05	0.00062	0.2473	0.0033	0.09252	0.00181
V-1.1	core	440	166	0.377	42	2	5.47E-05	0.00095	0.1179	0.0040	0.09404	0.00204
D-3.1	xeno	480	225	0.469	52	2	4.01E-05	0.00069	0.1523	0.0038	0.10415	0.00208
A-1.2	core	813	313	0.385	88	0	5.02E-06	0.00009	0.1197	0.0027	0.10596	0.00222
V-3.2	old rim	616	110	0.178	67	1	1.00E-05	0.00017	0.0807	0.0019	0.11039	0.00217
E-4.1	core	333	177	0.531	42	0	1.00E-05	0.00017	0.1636	0.0028	0.11820	0.00232
C-1.1	xeno	319	61	0.192	50	1	1.50E-05	0.00026	0.0591	0.0025	0.16109	0.00326
L-1.1	core	349	152	0.435	68	1	1.00E-05	0.00017	0.1239	0.0049	0.18787	0.00451
U-2.5	core	257	96	0.372	53	0	1.00E-05	0.00017	0.1178	0.0048	0.20026	0.00459
H-3.2	core	195	68	0.349	43	1	3.64E-05	0.00063	0.1120	0.0031	0.21283	0.00572
P-2.1	core	191	119	0.624	63	0	1.00E-05	0.00017	0.1779	0.0032	0.29970	0.00725
I-3.2	core	306	243	0.793	146	1	9.07E-06	0.00016	0.2292	0.0020	0.40167	0.00895

[1] SHRIMP spots are located on the following: core, core with magmatic rims; xeno, inherited grain (some with very thin rims); rim, euhedral magmatic rim

[2] mole fraction of total ^{206}Pb that is due to common Pb, based on ^{204}Pb; data have been corrected for common Pb according to procedures outlined in Stern (1997)

[3] uncertainties reported at one sigma and are calculated by numerical propagation of all known sources of error (Stern, 1997)

[4] ^{204}Pb-corrected ages

[5] 100 x (^{206}Pb/^{238}U age)/(^{207}Pb/^{206}Pb age)

[6] ^{207}Pb-corrected ages

mean square of weighted deviates [MSWD] = 1.3, probability of fit = 0.24), which is interpreted to be the crystallization age of the rock. Three discordant analyses on magmatic rims (H-3.1, T-1.2, AA-1.2; Table 2, Fig. 5) were not included in the weighted-average calculation. A weighted average of 481 ± 6 Ma was calculated using the ^{207}Pb-corrected ^{206}Pb/^{238}U ages.

Most of the ca. 479 Ma magmatic rims have quite high U contents (Table 2). Almost all of the rims are greater than 500 ppm U and most are greater than 1000 ppm U. These rims also have very low Th contents and corresponding very low Th/U ratios, almost consistently less than 0.10 and frequently less than 0.01 (Table 2). These data suggest that low Th/U ratios are not always indicative of metamorphic zircon growth.

A wide range of inherited ages was obtained from a total of fifteen cores and older rims, and includes Cambrian, Neoproterozoic, Mesoproterozoic, and Paleoproterozoic ages (Table 2, Fig. 5), with a high proportion of Neoproterozoic (960–560 Ma) results. The Middle River rhyolite has been interpreted to have formed by low-temperature

Table 2. (cont.)

Spot name	$^{207}Pb/^{235}U$	$\pm^{207}Pb/^{235}U$[3]	$^{207}Pb/^{206}Pb$	$\pm^{207}Pb/^{206}Pb$[3]	Ages (Ma) ± 1σ[4] $^{206}Pb/^{238}U$	$\pm^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$	$\pm^{207}Pb/^{206}Pb$	Conc.[5] (%)	Ages (Ma) ± 1σ[6] $^{206}Pb/^{238}U$	$\pm^{206}Pb/^{238}U$
Magmatic:											
AA-1.1	0.5935	0.0124	0.05663	0.00038	472.2	8.7	477.4	15.0	99	473.6	8.7
W-2.1	0.5889	0.0111	0.05553	0.00030	477.7	8.0	433.5	12.2	110	479.7	8.0
V-2.2	0.5968	0.0124	0.05581	0.00047	481.5	8.4	444.8	19.0	108	483.3	8.4
U-2.2	0.5991	0.0132	0.05673	0.00063	475.8	8.1	481.0	24.8	99	477.1	8.1
N-2.1	0.5684	0.0197	0.05436	0.00136	471.2	9.6	385.9	57.1	122	473.8	9.6
H-3.1	0.5160	0.0207	0.05912	0.00169	395.7	9.5	571.6	63.6	69	395.7	9.5
H-3.3	0.5740	0.0170	0.05586	0.00109	463.3	9.0	447.0	43.9	104	465.1	9.0
I-1.1	0.6006	0.0170	0.05502	0.00089	491.2	10.1	412.9	36.5	119	493.5	10.1
I-1.2	0.6079	0.0160	0.05615	0.00092	487.3	8.7	458.5	37.0	106	488.9	8.8
I-2.1	0.5844	0.0142	0.05662	0.00073	465.4	8.6	476.7	28.9	98	466.7	8.6
U-2.4	0.6144	0.0116	0.05585	0.00031	494.9	8.3	446.3	12.3	111	496.8	8.3
U-3.1	0.6060	0.0136	0.05619	0.00050	485.5	9.2	459.8	19.8	106	487.2	9.2
T-1.2	0.5848	0.0120	0.05816	0.00049	453.8	7.8	535.7	18.5	85	454.3	7.8
AA-1.2	0.5657	0.0114	0.05647	0.00043	452.1	7.7	471.0	16.9	96	453.5	7.7
Y-2.1	0.5886	0.0171	0.05489	0.00100	482.8	9.5	407.7	41.4	118	485.2	9.5
Inherited:											
T-3.1	0.6583	0.0268	0.05699	0.00174	518.6	11.6	491.2	68.9	106		
I-3.1	0.7226	0.0207	0.05774	0.00088	560.1	12.1	519.9	33.8	108		
W-3.1	0.7284	0.0222	0.05789	0.00116	563.0	11.1	525.8	44.4	107		
Q-2.1	0.7865	0.0197	0.06165	0.00083	570.4	10.7	662.1	28.9	86		
V-1.1	0.7736	0.0255	0.05967	0.00132	579.4	12.0	591.5	48.8	98		
D-3.1	0.8746	0.0223	0.06090	0.00082	638.7	12.2	635.8	29.2	100		
A-1.2	0.9006	0.0244	0.06164	0.00091	649.2	13.0	661.7	32.0	98		
V-3.2	1.0054	0.0257	0.06605	0.00092	675.0	12.6	808.1	29.5	84		
E-4.1	1.0717	0.0258	0.06576	0.00077	720.2	13.4	798.6	24.7	90		
C-1.1	1.6117	0.0434	0.07256	0.00112	962.8	18.1	1001.8	31.5	96		
L-1.1	1.9529	0.0831	0.07539	0.00243	1109.8	24.5	1078.9	66.1	103		
U-2.5	2.3453	0.0925	0.08494	0.00249	1176.7	24.7	1314.1	58.0	90		
H-3.2	2.7184	0.1092	0.09264	0.00247	1243.9	30.5	1480.5	51.5	84		
P-2.1	4.4121	0.1165	0.10677	0.00085	1689.8	36.1	1745.1	14.7	97		
I-3.2	8.5279	0.2094	0.15398	0.00122	2176.7	41.3	2390.6	13.5	91		

[1] SHRIMP spots are located on the following: core, core with magmatic rims; xeno, inherited grain (some with very thin rims); rim, euhedral magmatic rim

[2] mole fraction of total ^{206}Pb that is due to common Pb, based on ^{204}Pb; data have been corrected for common Pb according to procedures outlined in Stern (1997)

[3] uncertainties reported at one sigma and are calculated by numerical propagation of all known sources of error (Stern, 1997)

[4] ^{204}Pb-corrected ages

[5] 100 x ($^{206}Pb/^{238}U$ age)/($^{207}Pb/^{206}Pb$ age)

[6] ^{207}Pb-corrected ages

partial melting of a sedimentary protolith (Lentz, 1997), which is consistent with the prevalence and wide range of ages of inherited zircon obtained in this study.

DISCUSSION

The crystallization age of Middle River rhyolite is interpreted to be 479 ± 6 Ma. The SHRIMP analysis was successful in obtaining a crystallization age on a low-temperature volcanic rock with a very high proportion of inherited material of numerous ages. This age of 479 ± 6 Ma, which sets an upper limit on the age of the Miramichi Group, is slightly older than the oldest known rocks in the overlying Tetagouche Group (473–469 Ma; Sullivan and van Staal, 1996; Rogers et al., 1997; Rogers et al., in press a). In addition, it constrains the timing of initial volcanism in the area, suggesting the presence of a hiatus between the Miramichi and Tetagouche groups (van Staal et al., in press). The youngest zircon xenocryst in Middle River rhyolite (ca. 519 Ma) also constrains the maximum age for the Miramichi Group.

Figure 6 presents a cumulative probability plot of inherited zircon ages from Middle River rhyolite (this paper), and Ordovician plutons in the Bathurst mining camp area

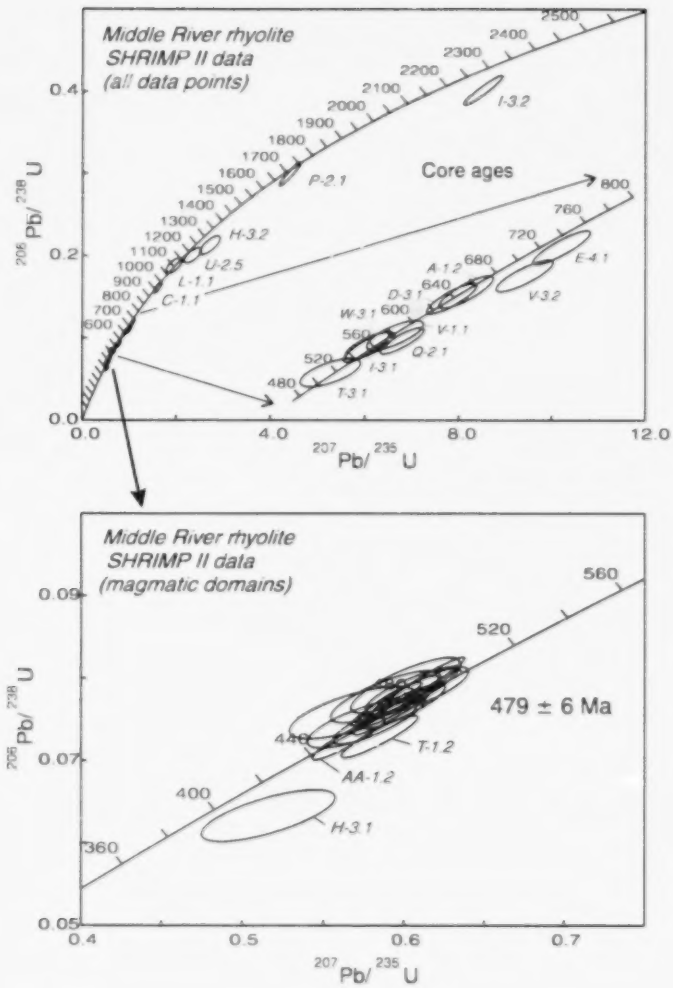

Figure 5.

U-Pb concordia diagram of SHRIMP II analyses of sample z4416, with error ellipses at 2σ.

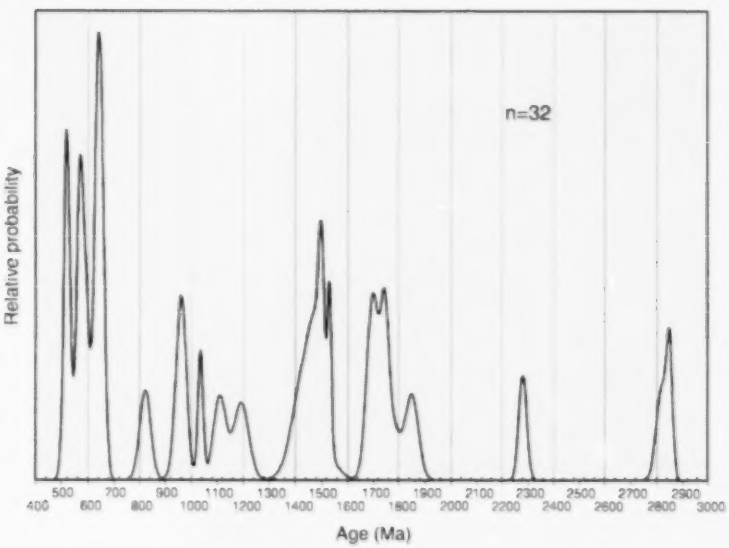

Figure 6.

Cumulative probability plot of inherited zircon ages from Middle River rhyolite (this paper) and Ordovician plutons in the Bathurst mining camp area (Roddick and Bevier, 1995; McNicoll et al., in press). Only data that are less than 5% discordant are plotted in the diagram. The plot presents $^{206}Pb/^{238}U$ ages for data less than 800 Ma, and $^{207}Pb/^{206}Pb$ ages for data greater than 800 Ma.

(Roddick and Bevier, 1995; McNicoll et al., in press). Inheritance ages range from Cambrian through to Archean, suggesting the presence of complex, old basement. Similar inherited ages have been obtained from cobbles found in the Vallée Lourdes Member of the Nepisguit Falls Formation of the Tetagouche Group, and in the Late Neoproterozoic to Lower Cambrian (554–543 Ma) Upsalquitch gabbro in the northwestern part of Bathurst mining camp (van Staal et al., 1996). Upsalquitch gabbro is inferred to represent a tectonic fragment of Gander basement (van Staal et al., 1996).

The range of inherited ages from Middle River rhyolite and the synvolcanic Ordovician plutons, particularly the abundance of xenocrysts of Neoproterozoic–Cambrian age, combined with isotopic and geochemical data (Whalen et al., 1998), is not compatible with Laurentia as a possible basement to the Gander zone. Rocks with an eastern Laurentian margin provenance would be characterized by a dominance of 1.5–1.0 Ga (Mesoproterozoic) zircon grains, accompanied by 615–550 Ma (late Neoproterozoic) grains and a paucity or absence of 1.6–1.5 Ga (G. Ross, pers comm), 850–600 Ma, and 543–520 Ma zircons (Neoproterozoic and Early Cambrian, respectively; van Staal et al., 1996 and references therein). In contrast, rocks with an Avalonian or other Gondwanan provenance should contain 850–550 Ma zircon grains (Neoproterozoic), possibly accompanied by grains of Cambrian, Mesoproterozoic (1.6–1.0 Ga), and Archean age. The presence of late Neoproterozoic to Early Cambrian inherited zircon in Middle River rhyolite and the synvolcanic Ordovician plutons is significant, as it provides a link with igneous rocks of similar age in the New River–Brookville belt of the New Brunswick Avalon zone (van Staal et al., 1996 and references therein; Johnson and McLeod, 1996; White and Barr, 1996; Barr and White, 1996; Currie and McNicoll, 1999).

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